

**American Concrete Institute®**  
*Advancing concrete knowledge*

## What About Adhesive Anchors? Part 2(B)

ACI Spring 2010 Xtreme Concrete Convention  
 March 21 - 25, Chicago, IL

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## ACI Web Sessions

The audio for this web session will begin momentarily and will play in its entirety along with the slides.

However, if you wish to skip to the next speaker, use the scroll bar at left to locate the speaker's first slide (indicated by the icon in the bottom right corner of slides 9, 34, and 62). Click on the thumbnail for the slide to begin the audio for that portion of the presentation.


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**ACI WEB SESSIONS**

## ACI Web Sessions

ACI is bringing you this Web Session in keeping with its motto of "Advancing Concrete Knowledge." The ideas expressed, however, are those of the speakers and do not necessarily reflect the views of ACI or its committees.

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  - Salt Lake City, UT - 10/13
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  - Orlando, FL - 12/8
  - Louisville, KY - 11/4
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  - Atlanta, GA - 12/2
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## ACI Web Sessions

This ACI Web Session includes three speakers presenting at the ACI Xtreme Concrete convention held in Chicago, IL, March 21<sup>st</sup> through 25<sup>th</sup>, 2010. Additional presentations will be made available in future ACI Web Sessions.

Please enjoy the presentations.



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## What About Adhesive Anchors? Part 2(B)

ACI Spring 2010 Xtreme Concrete Convention  
March 21 - 25, Chicago, IL



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**Hannes Spieth** is Director of Technology Transfer and Research at Fischerwerke GmbH & Co. in Waldachtal, Germany. He studied civil engineering at the Universities of Stuttgart (Germany), Calgary (Canada) and Gainesville (USA). After completing his studies, he spent 6 years as a research assistant at the IWB (anchorage/fastening division) of the University of Stuttgart, and completed his Ph.D. thesis there. As a guest lecturer and post-doctoral researcher at the University of Canterbury in Christchurch (New Zealand), he focused on earthquake engineering. Dr. Spieth joined Fischerwerke in 2004, and is currently responsible for research and technology transfer. He is a member of several European and German scientific and approval development committees, as well as the CAMA and ACI.



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### Evaluation of Long-Term Behavior of Bonded Anchors - Approval Testing vs. Long-Term Results Dr. Hannes A. Spieth

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### Structure

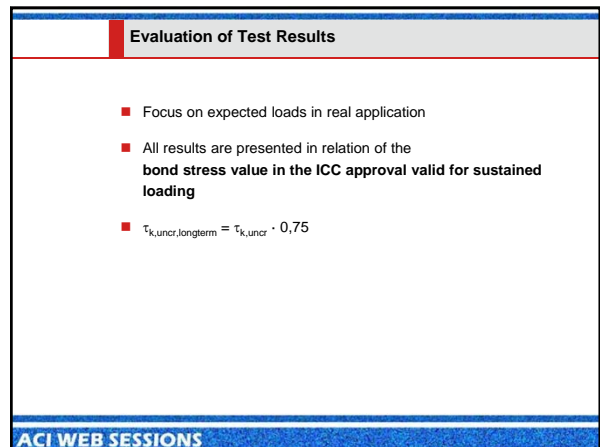
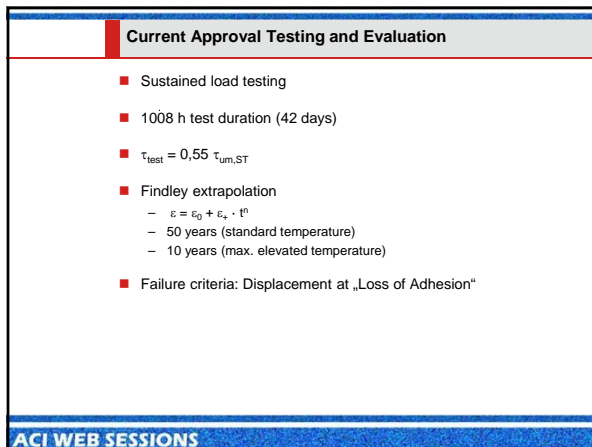
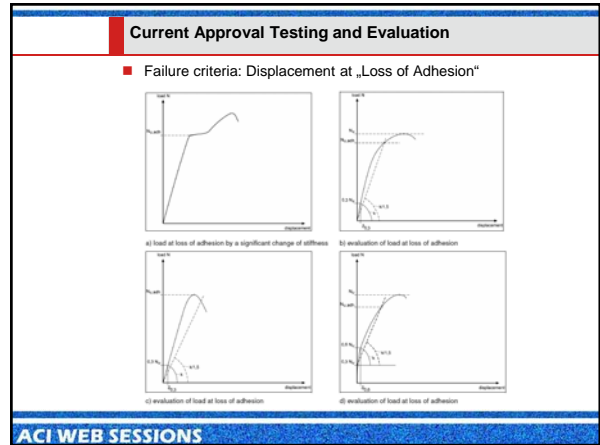
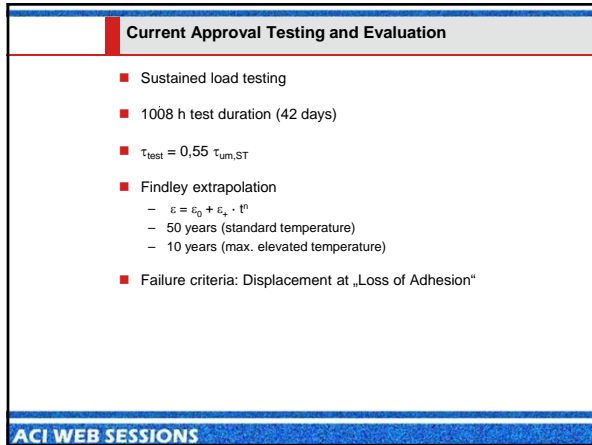
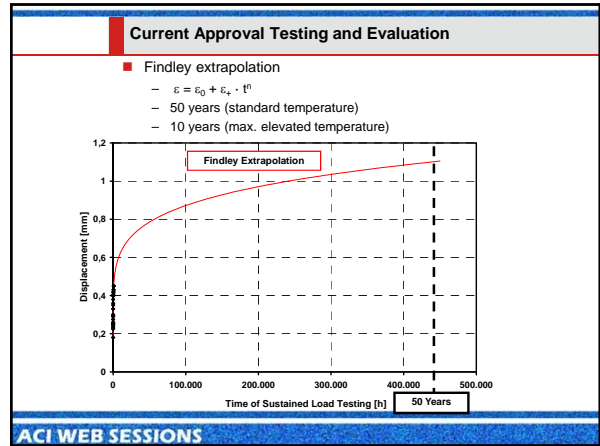
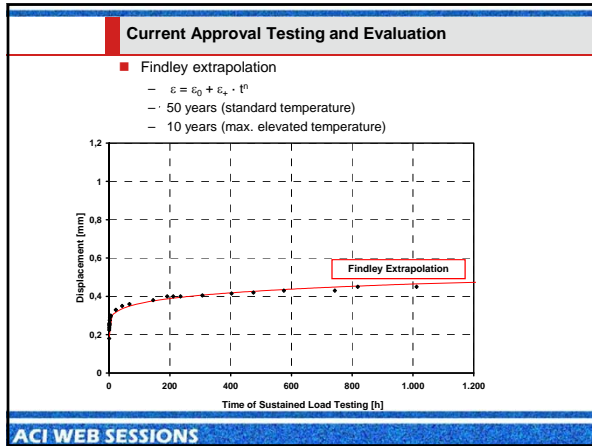
- Current Sustained Load Approval Testing
- Sustained Load Testing beyond Approval Regulations
- Evaluation of Conservatism in Current Approval Testing
- Approval Values versus Long-Term Sustained Load Test Results

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### Current Approval Testing and Evaluation

- Sustained load testing
- 1008 h test duration (42 days)
- $\tau_{test} = 0,55 \tau_{um,ST}$
- Findley extrapolation
  - $\epsilon = \epsilon_0 + \epsilon_s \cdot t^n$
  - 50 years (standard temperature)
  - 10 years (max. elevated temperature)

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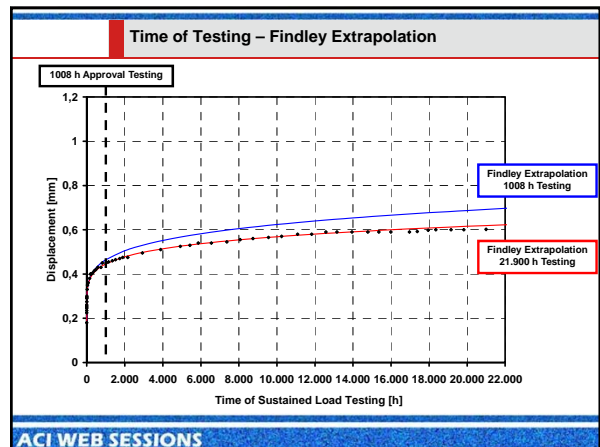
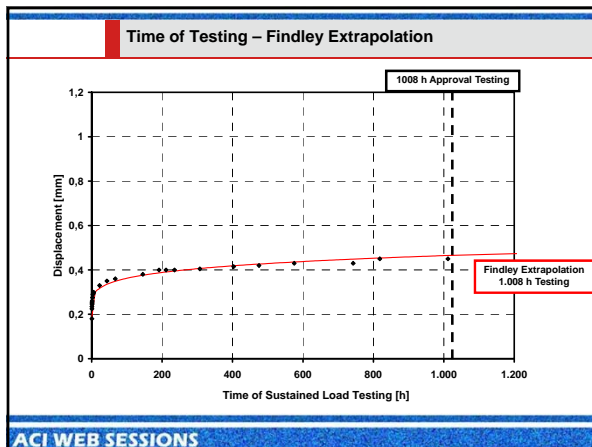
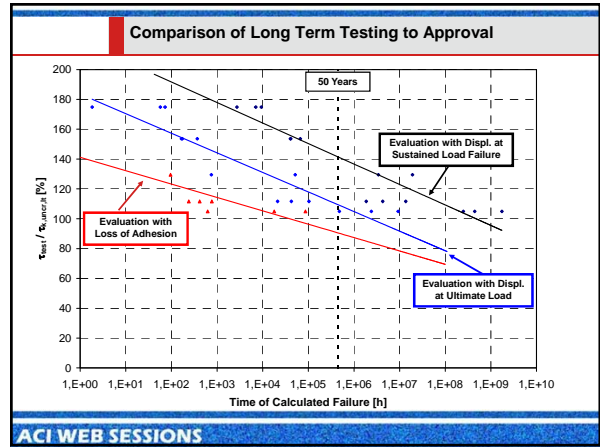
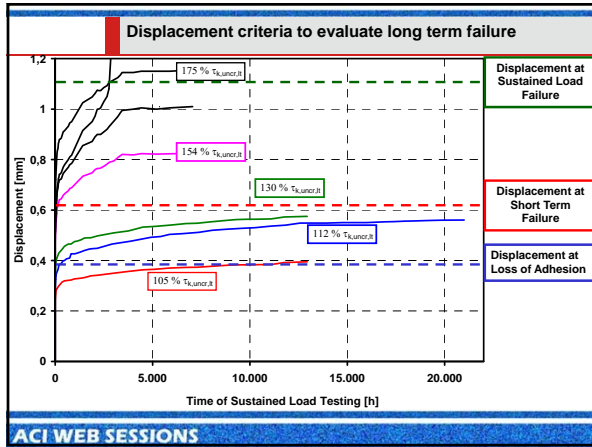
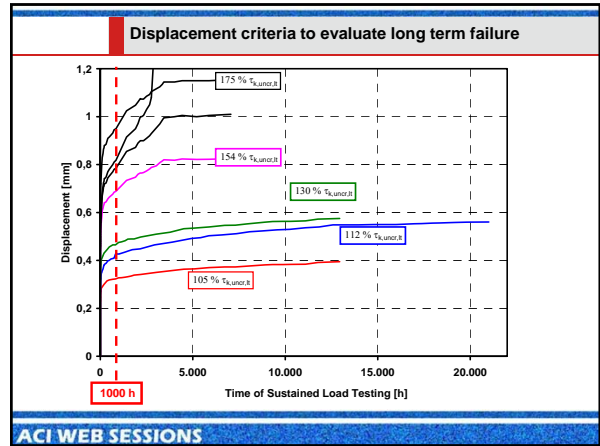
### Performed Test Program

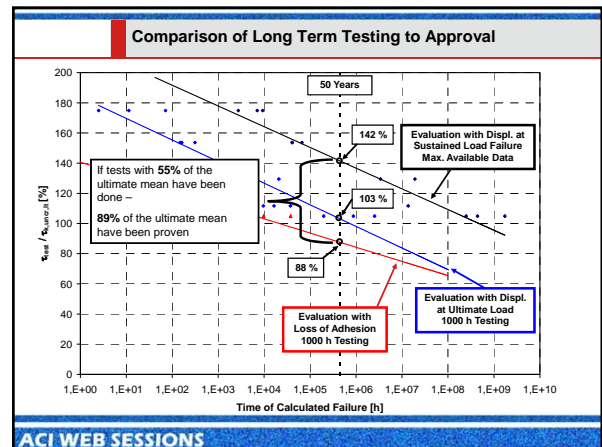
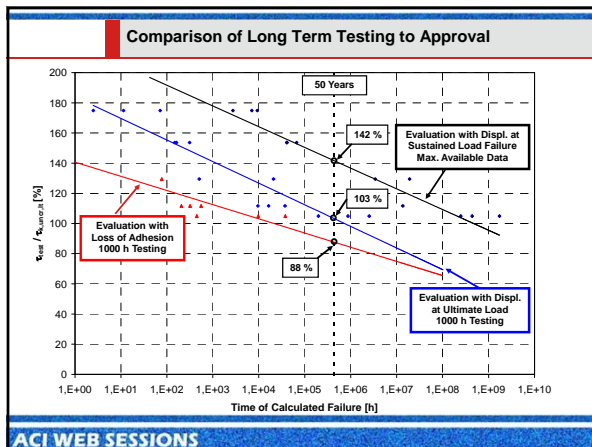
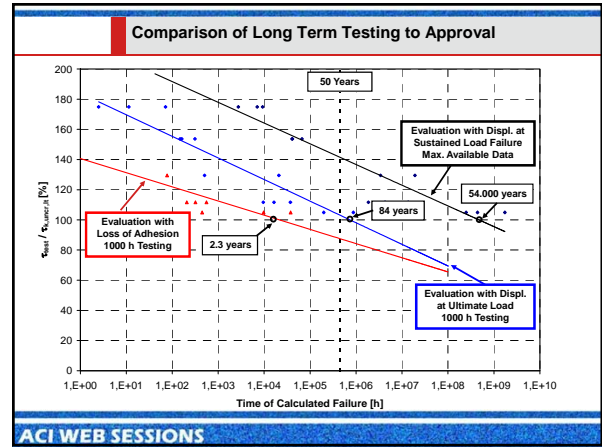
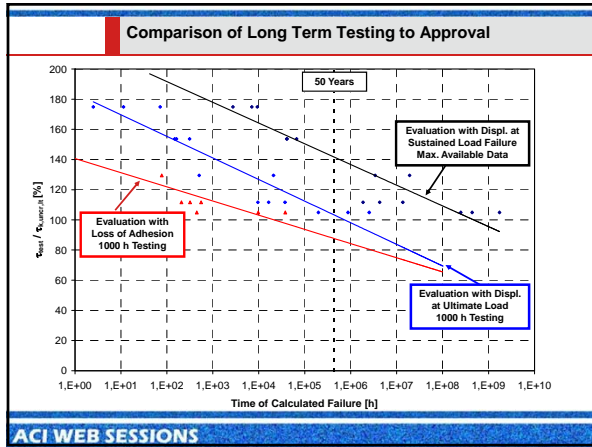
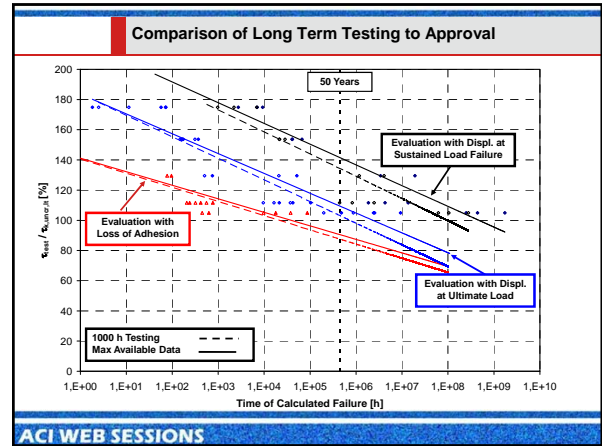
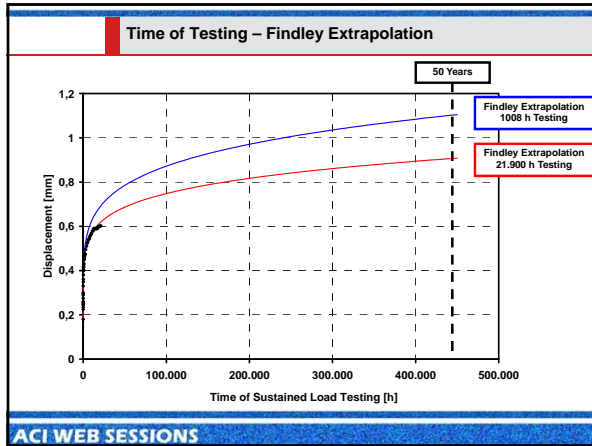
- Product with Approval
- Vinylester Injection System with additional cement content

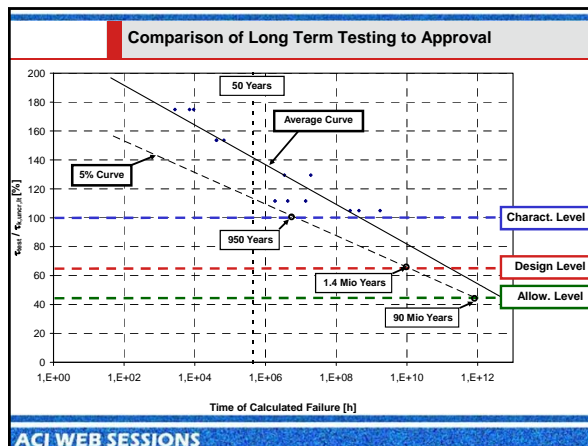
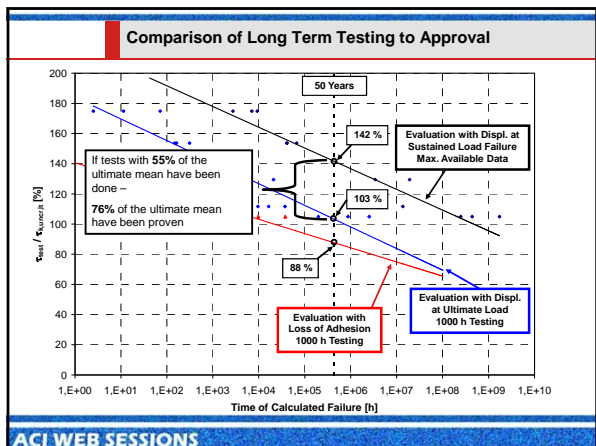
Load level in relation to characteristic long term bond strength in ICC approval $\tau_{test} / \tau_{ultimate}$	Load level in relation to design long term bond strength in ICC approval $\tau_{test} / \tau_{design}$	Duration of sustained load testing	Number of tests
105 %	161 %	12.900 h	3
112 %	172 %	21.000 h	3
130 %	200 %	12.900 h	2
154 %	236 %	7.100 h	3
175 %	269 %	7.100 h	3

(1 failure at 3.200 h)

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- ### Summary
- Evaluation of Current Approval Tests
    - Extrapolation approach is significantly conservative (1000 h testing compared to long-term test results)
    - Failure Criteria „Loss of Adhesion“ and „Displacement at Ultimate Failure Load“ are significant on the safe side
    - Testing at 55 % of ultimate mean value with current approval evaluation corresponds to 76 to 89 % of the ultimate mean value
  - Evaluation of Approval Values versus Sustained Load Test Results
    - Time – Failure Curves show for current design regulations at standard temperature and tested system significant safety margin

**Adham El Menoufy** is a graduate student working on his Master's degree at the University of Waterloo, in Waterloo, Ontario, Canada.

## Effect of Environmental Exposure on the Creep Behavior of Adhesive Anchors

Adham M. El Menoufy,  
Khaled A. Soudki,  
Ahmed K. El Sayed and  
Hannah Schell

- ### INTRODUCTION
- Anchoring systems for concrete are comprised of: cast-in-place, and post-installed anchors.
  - Post-installed anchors:
    - Mechanical systems (expansion and undercut)
    - Bonded (adhesive and grouted) systems.
      - Load transfer is ensured by bond stresses between the anchor, adhesive and concrete along embedment length.
      - Adhesive anchors can be a threaded rod or deformed steel rebar.
      - Different products are used to install adhesive anchors including polymers (epoxies, polyesters, or vinylesters).

## INTRODUCTION

- Tu and Kruger, (1996) reported that water is a harmful factor for epoxy adhesives and noted severe bond strength deterioration of joints subjected to water immersion.
- Higgins and Klingner, (1998) tested the effect of UV exposure and acid rain wetting and drying on the bond strength of a single adhesive anchor, and found no significant impact on the tensile behavior of the anchor to such exposure.

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## INTRODUCTION

- Cook and Konz, (2001) experimentally investigated the sensitivity of 20 adhesive products to various installation and service conditions through confined tension tests. Findings showed some general trends for products with similarities in chemical composition. However, responses to various conditions and factors varied significantly making it unreliable to make prediction based on chemical formulation.
- Meline et al., (2006) evaluated the creep performance of epoxy adhesive anchor systems with epoxy-coated steel rebars at elevated temperature on three types of adhesives. Two out three failed to satisfy the ICBO-AC-058 requirements

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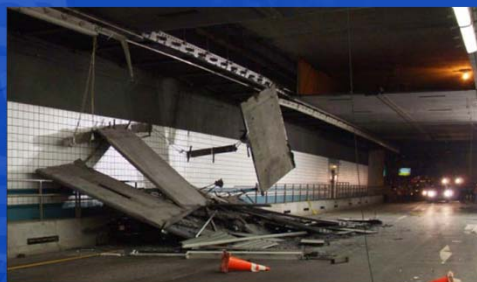
## INTRODUCTION

On July 10<sup>th</sup> 2006, in Interstate 90 (I-90) connector tunnel in Boston, Massachusetts. As the car approached the end of the tunnel, a section of the suspended concrete ceiling detached from the tunnel roof and fell onto the vehicle and the roadway.

The National Transportation Safety Board determined that the probable cause of the collapse was the use of an epoxy anchor adhesive with poor creep resistance.

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## INTRODUCTION



(Highway Accident Report NSTB/HAR-07/02, 2007)

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## INTRODUCTION

Limited research on the long-term performance of adhesive anchors was reported in the literature.

Prompted by concerns with long term durability of adhesive anchors in view of the US experience, and a desire to develop effective material prequalification requirements.

The University of Waterloo, in collaboration with the Ministry of Transportation of Ontario, conducted this research study to investigate the long-term creep behavior of adhesive anchors under sustained tensile loads.

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## OBJECTIVES OF STUDY

The main objective of this research study is to evaluate the performance of epoxy and acrylic-based adhesive anchor systems.

The study focuses on the creep performance of these anchor systems under sustained tensile loads combined with different exposure condition, and on the tensile capacity after exposure to different environmental conditions.

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### EXPERIMENTAL PROGRAM

PHASE		Type A	Type B	Type C
Phase I : Static testing at room temperature	Sustained load = 0% ultimate	3	3	3
Phase II : Creep test at room temperature	Sustained load = 40% ultimate	3	3	3
Phase III : Creep test under moisture exposure	Sustained load = 40% ultimate	3	3	3
Phase IV : Creep test under freeze-thaw cycles	Sustained load = 40% ultimate	3	3	3
Total number of specimens		18	18	18

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### EXPERIMENTAL PROGRAM, Cont.

#### Test specimens

- Cylindrical concrete block 12 inch in diameter and 8 inch in height.
- Anchors are 15 M deformed steel reinforcing bar, embedded to a depth of  $8d_b$  (5 inches)

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### EXPERIMENTAL PROGRAM Cont.

#### Anchor installation

Three adhesive materials were used for anchors installation:

- **Type A** - Fast setting two component methyl methacrylate
- **Type B** - Fast setting two part epoxy adhesive
- **Type C** - Standard set two part epoxy adhesive
- witnessed by a representative for each manufacturer.

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### EXPERIMENTAL PROGRAM Cont.

#### Creep Test Setup - ambient temperature & moisture exposure

Specimens are tested in a steel frame that is designed to magnify a dead load through a series of lever arms.

Axial tension load on the anchors was approximately 32 kN (40% of the yield strength of the anchor).

All steel frames were pre-calibrated.

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### EXPERIMENTAL PROGRAM Cont.

#### Creep Testing Setup for Freeze/Thaw cycling

The second testing frame relied on compression coil springs and rod assembly to apply the load.

The coil springs used had a capacity of 40kN at 1.5 inch of compression displacement.

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### EXPERIMENTAL PROGRAM Cont.

#### Static Pullout Testing Setup

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### STATIC PULLOUT RESULTS

- Specimens with all 3 adhesives behaved in a similar manner up to yielding of the anchor.
- Specimens with Type B and Type C adhesives exhibited stronger ultimate capacities, forcing the anchor to fail by rupture prior to bond failure.
- All three specimens with Type A adhesive failed by bond.

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### STATIC PULLOUT RESULTS

Specimen	Ultimate Load (kN)		Failure Mode
		Average	
A-R-1	132	120.7	Yielding of the anchor followed by bond failure
A-R-2	122		Yielding of the anchor followed by bond failure
A-R-3	108		Yielding of the anchor followed by bond failure
B-R-1	133	133.3	Yielding of the anchor followed by anchor rupture
B-R-2	133		Yielding of the anchor followed by anchor rupture
B-R-3	134		Yielding of the anchor followed by concrete splitting
C-R-1	129	131.7	Yielding of the anchor followed by anchor rupture
C-R-2	133		Yielding of the anchor followed by anchor rupture
C-R-3	133		Yielding of the anchor followed by anchor rupture

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### CREEP TEST RESULTS

- The creep tests were carried out under a sustained load of 32kN or 40% of the yield strength of the anchor for a minimum period of 90 days.
- Specimens with each type of adhesive were subjected to three types of exposure:
  - Ambient temperature
  - Moisture exposure (by ponding)
  - Freeze/thaw cycles with the presence of moisture (16hrs freezing @ -20C, 8hrs thawing @ +20C)

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### CREEP TEST RESULTS, Cont. Specimens with Type A adhesive

Environmental exposure caused significant variation in the measured creep displacement:

- Ambient temperature - consistent response with decreasing creep displacement rate over time.
- Moisture exposure - significant increase in initial elastic displacement and in the overall creep displacement.
- Freeze/thaw cycling - increased creep displacement and an increasing rate of creep displacement over time.

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### CREEP TEST RESULTS, Cont. Specimens with Type A adhesive

The graphs show that moisture exposure leads to the highest creep displacement, followed by freeze/thaw cycles, and ambient temperature shows the lowest displacement. The comparison graph shows that the combination of moisture and freeze/thaw cycles results in the highest overall creep displacement.

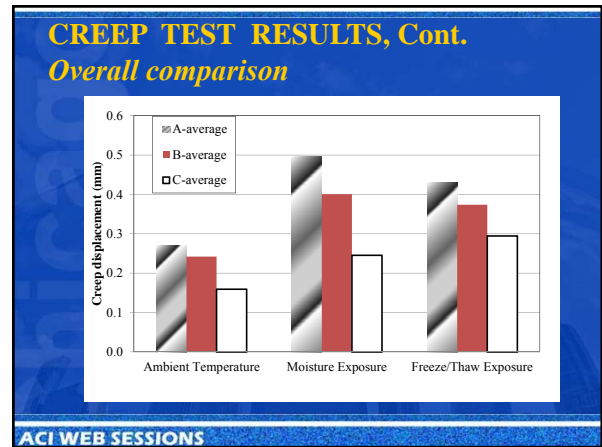
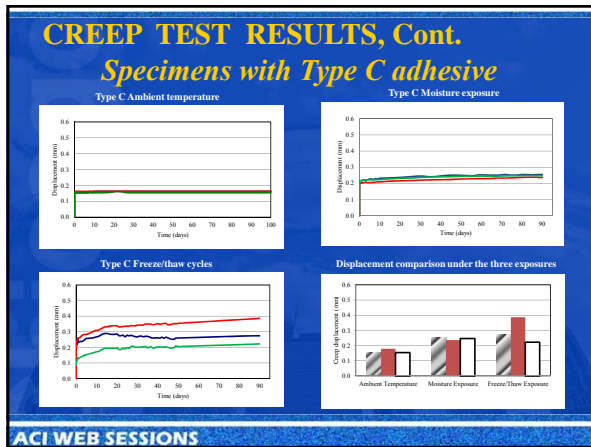
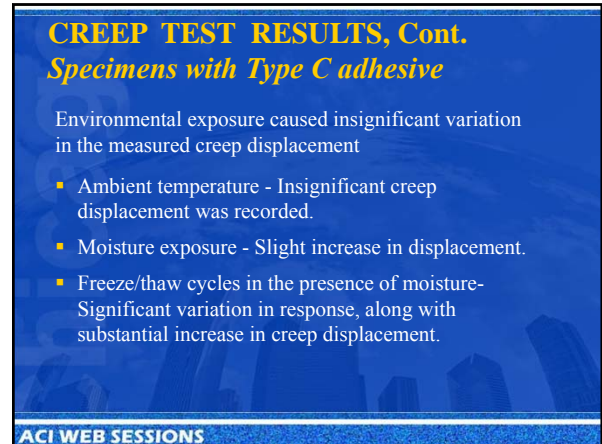
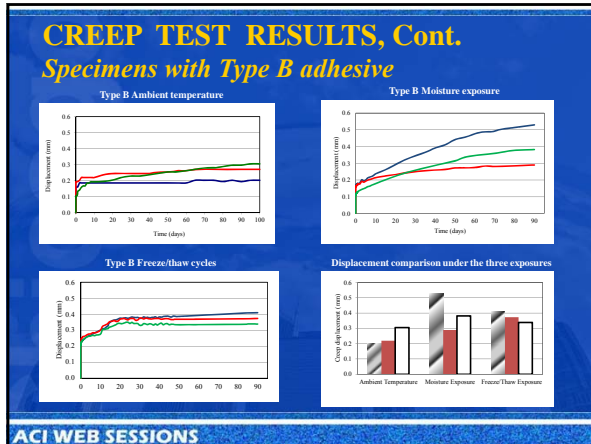
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### CREEP TEST RESULTS, Cont. Specimens with Type B adhesive

Environmental exposure led to inconsistent behavior significant variation in the measured creep displacement:

- Moisture exposure - higher average overall creep displacement with an increasing rate with time, with a widely variable response within the three specimens.
- Freeze/thaw cycles in presence of moisture – slightly higher overall average creep displacement.

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### CONCLUSION

- All adhesive types had lower creep displacements under ambient exposure than moisture or freeze-thaw exposure
- Types A and B showed a significant increase in creep displacement when exposed to moisture.
- Freeze/thaw cycles did not have much of an effect on Type B, slightly affected Type C but significantly affected creep response for Type A.
- Type C (Standard set two part epoxy) adhesive appears to be superior in terms of creep behavior over both the fast setting Types A and B adhesives.
- Types B and C adhesives exhibit higher capacity compared to the acrylic based Type A.

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### CONCLUSION, Cont.


- Further extrapolation and analysis of the test data is required to assess the effect of such conditions on the anchor system within their intended service life.
- Additional testing on a wider range of adhesives should be done to incorporate these environmental impacts in a design model.

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## ACKNOWLEDGMENT

This research was funded by the Ministry of Transportation Ontario through a research contract under the Highway Infrastructure Innovations Funding Program (HIIFP).

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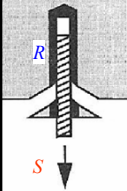


**Andreas Unterweger** is currently completing his post-doctoral studies at The University of Tokyo, Institute of Industrial Science. Previously, he was a Professor at BOKU University of Natural Resources and Life Sciences in Vienna, Austria. Dr. Unterweger holds degrees in civil, structural, and industrial engineering. He earned his Ph.D. in 2008, focusing on anchorage in concrete. His areas of expertise are fracture mechanics, electronic speckle pattern interferometry, experimental procedure, and the Spanish and Japanese languages. He is the recipient of the Amann Stipendium award (2002), and the Klaus Fischer Prize for Innovation and Technology (2010).

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### Reliability Assessment of Bonded Anchor Systems

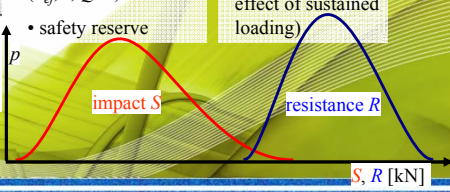
presented by Andreas Unterweger, Ph.D.



**Content**

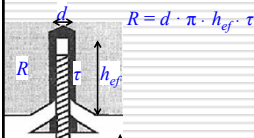
- distribution function
- sensitivity analysis ( $h_{ef}$ ,  $\tau$ ,  $Q/G$ )
- safety reserve

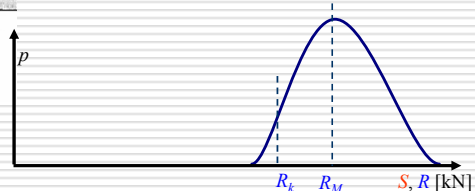
- new introduced prefactor  $\kappa$  (index of safety reserve/ effect of sustained loading)



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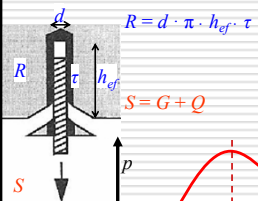
### Basics of the Calculation



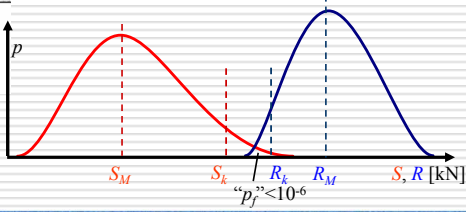
$$R = d \cdot \pi \cdot h_{ef} \cdot \tau$$


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### Basics of the Calculation

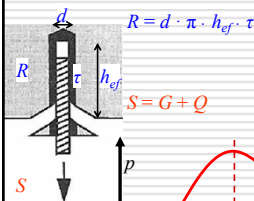


$$R = d \cdot \pi \cdot h_{ef} \cdot \tau$$

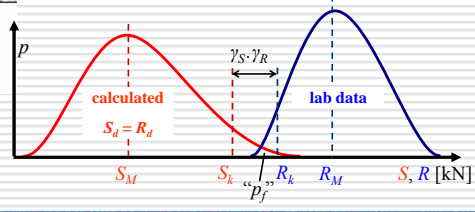
$$S = G + Q$$


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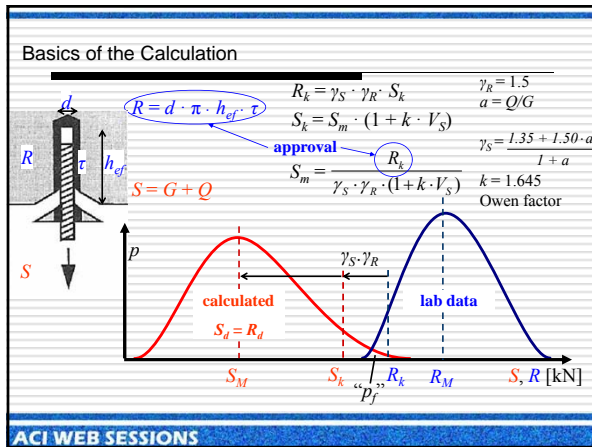
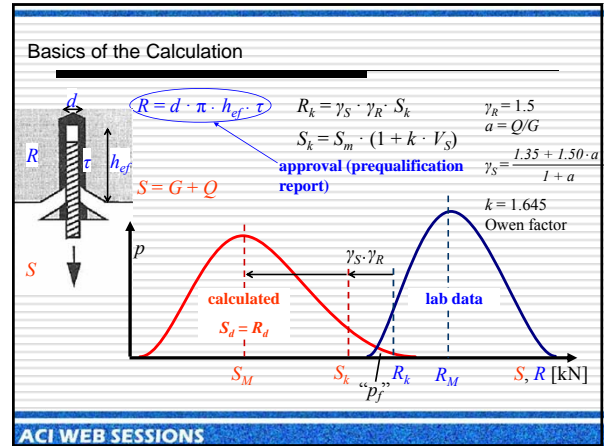
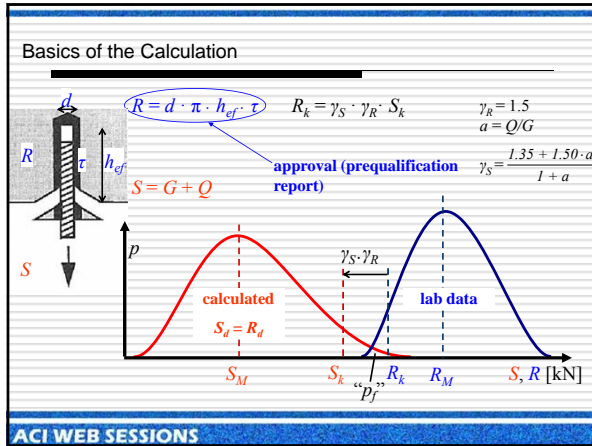
### Basics of the Calculation



$$R = d \cdot \pi \cdot h_{ef} \cdot \tau$$

$$S = G + Q$$


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### Parameter for Load Effect and Resistance

Tab. 1: Input parameters for the load effect

Parameter	Coefficient of Variation $V$ [%] <sup>1)</sup>	Type of Distribution
Dead loads $N_{EG}$	5	Normal Dist.
Live loads $N_{EQ}$	15	Log-Normal Dist.

<sup>1)</sup> Values from the JCSS probabilistic model code - part 2: "Load models"

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### Parameter for Load Effect and Resistance

Tab. 1: Input parameters for the load effect

Parameter	Coefficient of Variation $V$ [%] <sup>1)</sup>	Type of Distribution
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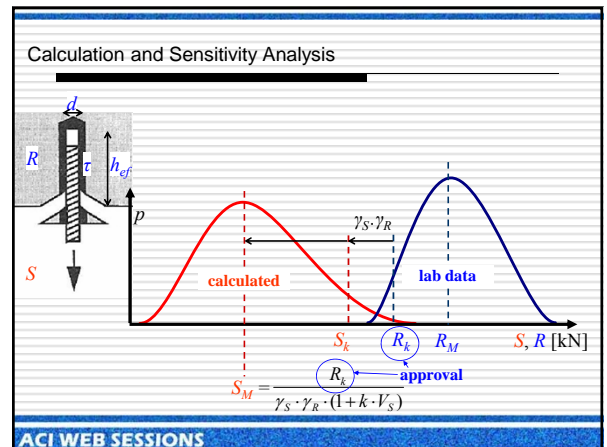
<sup>1)</sup> Values from the JCSS probabilistic model code - part 2: "Load models"

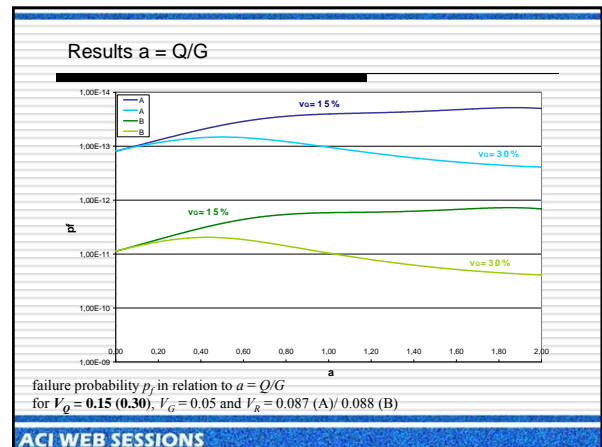
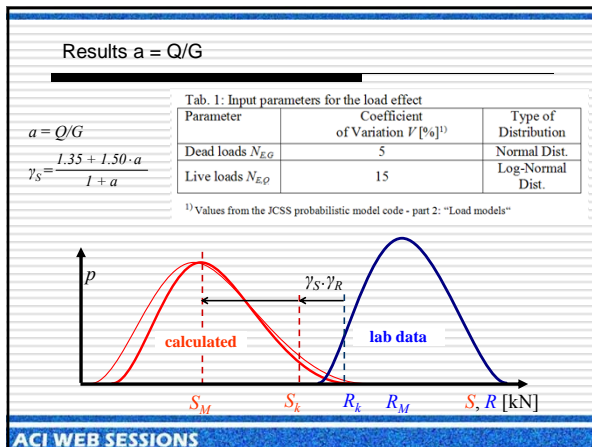
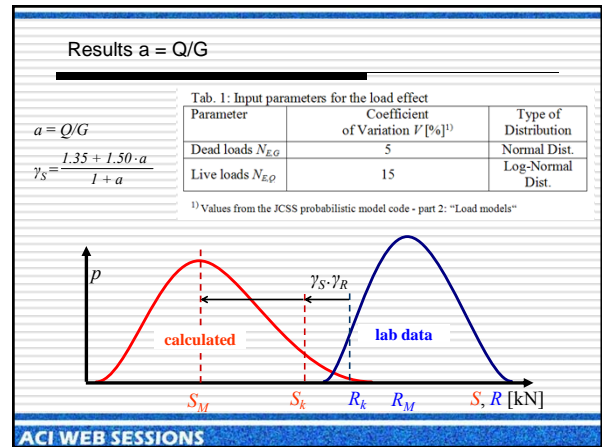
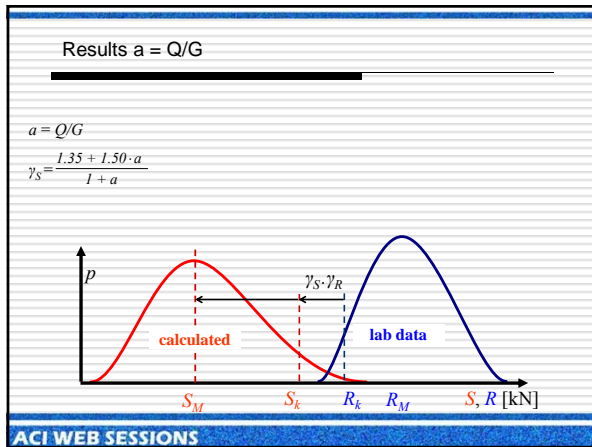
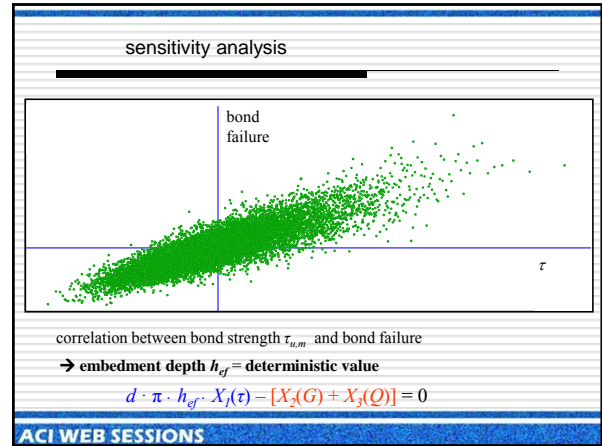
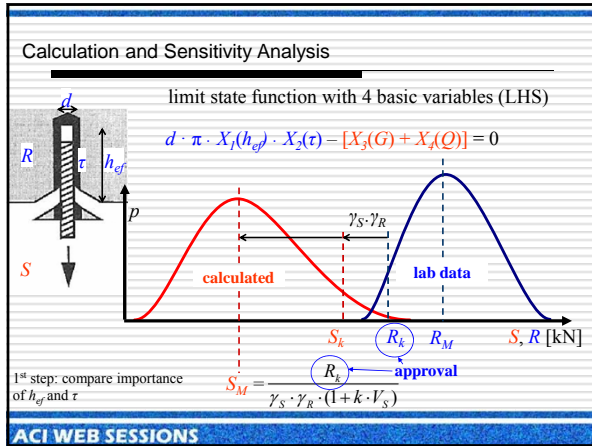
Tab. 2: Input parameter for the resistance

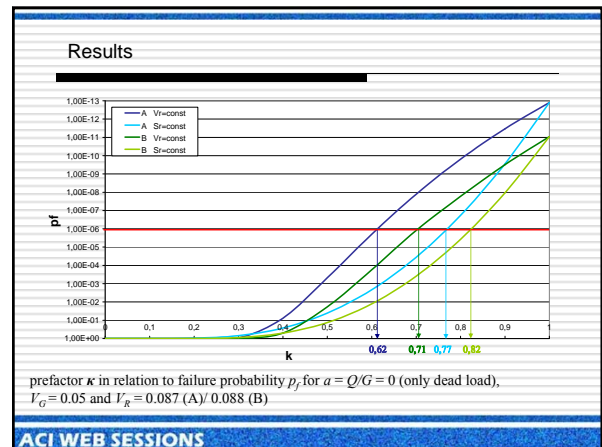
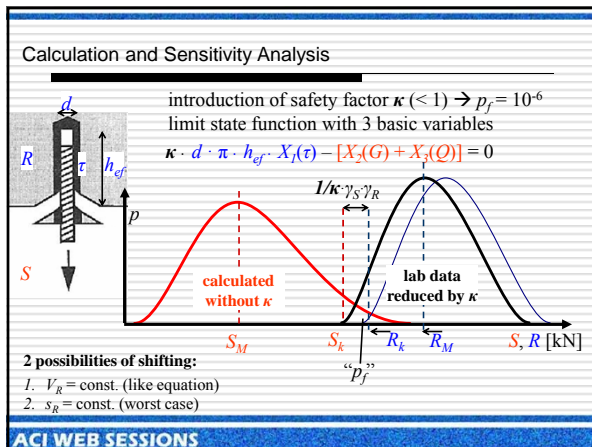
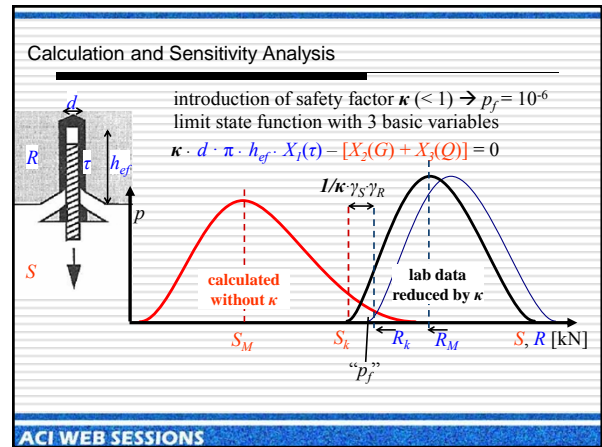
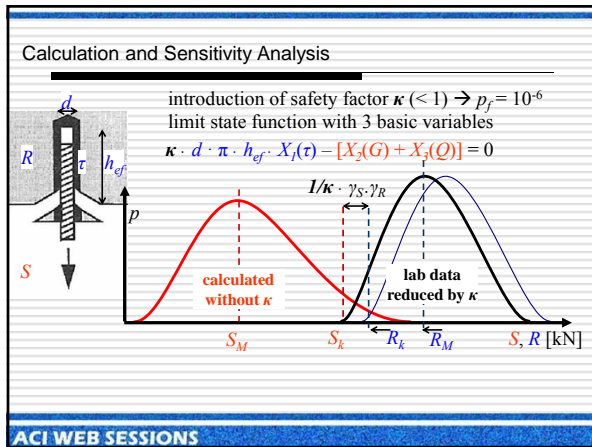
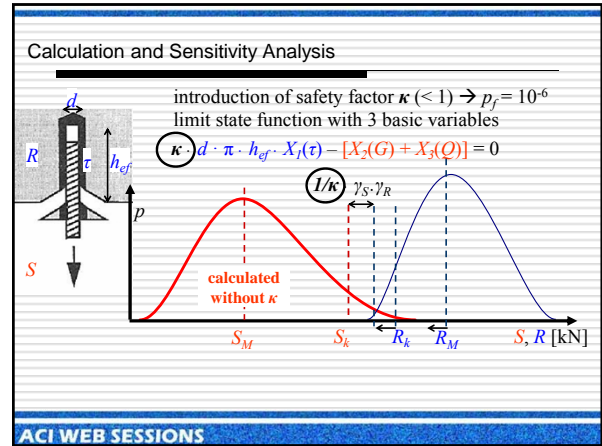
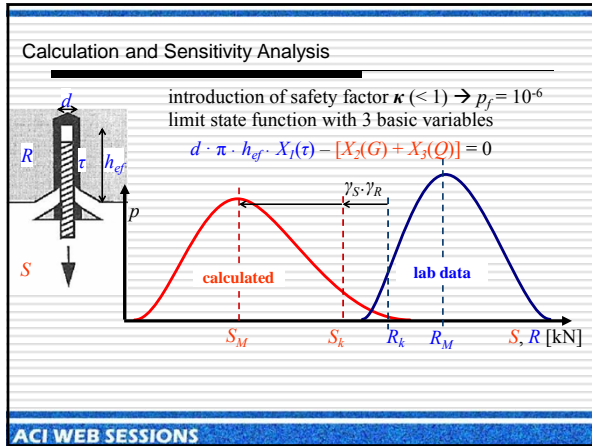
Parameter	Product	Unit	$X_c$ <sup>1)</sup>	$V$ [%]	Type of Distribution
Bond strength $\tau_{a,m}$	A B	[N/mm <sup>2</sup> ]	14.6   13.7	8.8 <sup>1)</sup>   8.7 <sup>1)</sup>	LND
Concrete strength $f_{ck,cs1}$	C20/25		25	15 <sup>2)</sup>	LND
Diameter $d$	M12	[mm]	12	deterministic	-
Embedment depth $h_{ef}$	-		110	5	ND

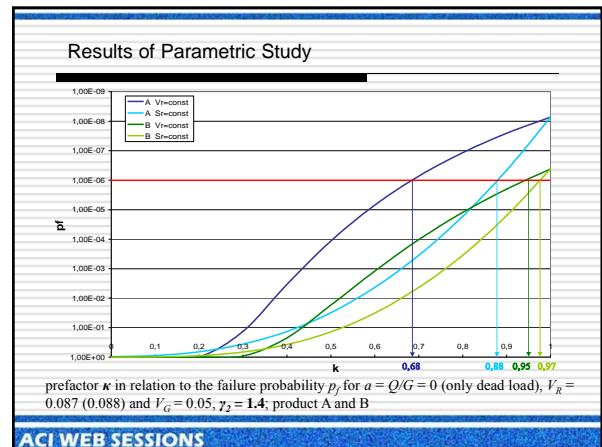
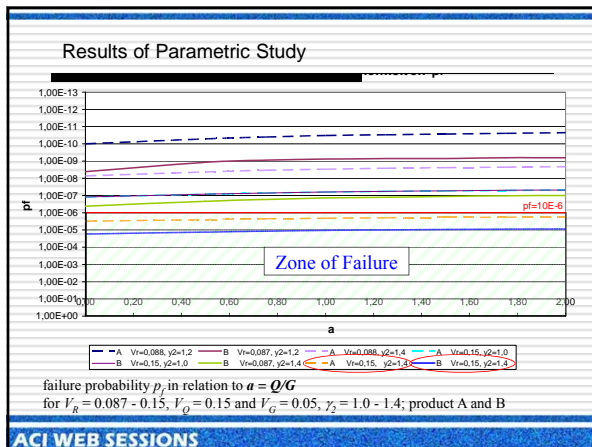
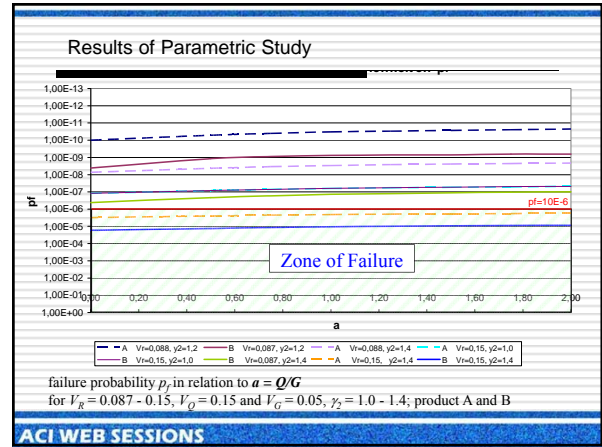
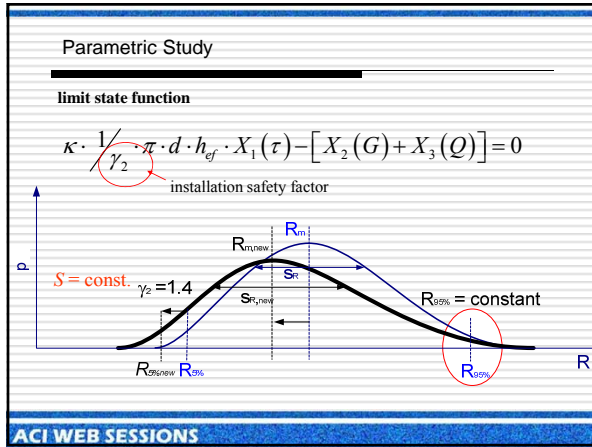
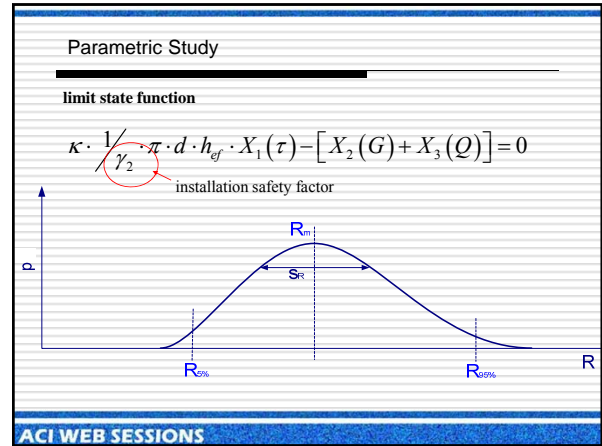
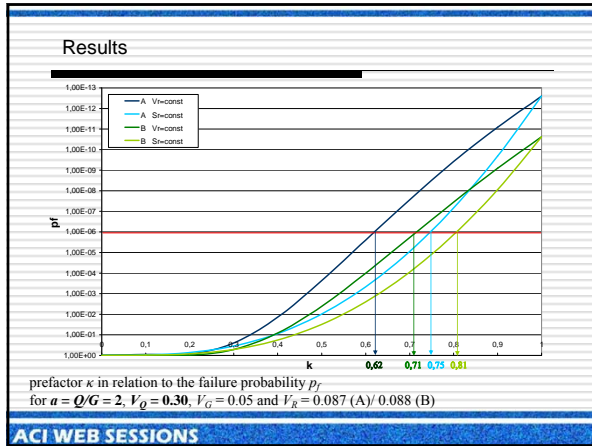
<sup>1)</sup> Values from the Evaluation Report of the Injection system A and B  
<sup>2)</sup> Values from the JCSS probabilistic model code - part 3: "Resistance models"

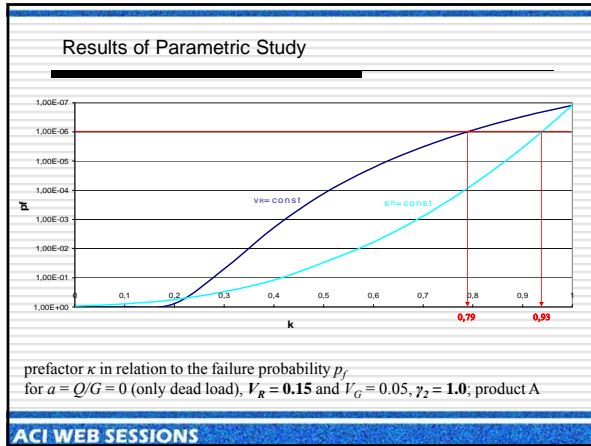
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### Summary of the Parametric Study

Tab. 3: Sets of parameters and associated prefactors  $\kappa$

Parameter	Units	Parameters for the basic calculation				prefactor $\kappa$	
		Value	$V$ [%]	Distribution	A	B	
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.62	0.71	
Live load $N_{EG}$	[N]	15	15	log-Normal	0.77 <sup>1)</sup>	0.82 <sup>1)</sup>	
Bond strength $\tau_{sm}$   A   B	[N/mm <sup>2</sup> ]	14.6   13.7	8.8   8.7	log-Normal	-	-	
Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-	

<sup>1)</sup> Second prefactor  $\kappa$  corresponds to  $s_R = \text{const}$ .

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### Summary of the Parametric Study

Tab. 3: Sets of parameters and associated prefactors  $\kappa$

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Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-	

Modified parameters						
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.62	0.71
Live load $N_{EG}$	[N]	30	30	log-Normal	0.62	0.71
Bond strength $\tau_{sm}$   A   B	[N/mm <sup>2</sup> ]	14.6   13.7	8.8   8.7	log-Normal	0.75 <sup>1)</sup>	0.81 <sup>1)</sup>
Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-

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Tab. 3: Sets of parameters and associated prefactors  $\kappa$

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Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-	

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Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-

Modified parameters						
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.68	0.95
Live load $N_{EG}$	[N]	15	15	log-Normal	0.68	0.95
Bond strength $\tau_{sm}$   A   B	[N/mm <sup>2</sup> ]	14.6   13.7	8.8   8.7	log-Normal	0.88 <sup>1)</sup>	0.97 <sup>1)</sup>
Installation safety factor $\gamma_2$	[-]	1.4	-	-	-	-

<sup>1)</sup> Second prefactor  $\kappa$  corresponds to  $s_R = \text{const}$ .

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### Summary of the Parametric Study

Tab. 3: Sets of parameters and associated prefactors  $\kappa$

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Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-	

Modified parameters						
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.62	0.71
Live load $N_{EG}$	[N]	30	30	log-Normal	0.62	0.71
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Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-

Modified parameters						
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.68	0.95
Live load $N_{EG}$	[N]	15	15	log-Normal	0.68	0.95
Bond strength $\tau_{sm}$   A   B	[N/mm <sup>2</sup> ]	14.6   13.7	8.8   8.7	log-Normal	0.88 <sup>1)</sup>	0.97 <sup>1)</sup>
Installation safety factor $\gamma_2$	[-]	1.4	-	-	-	-

Modified parameters						
Dead load $N_{EG}$	[N]	$f(a = Q/G)$	5	Normal	0.79	-
Live load $N_{EG}$	[N]	15	15	log-Normal	0.79	-
Bond strength $\tau_{sm}$   A   B	[N/mm <sup>2</sup> ]	14.6   13.7	15	log-Normal	0.93 <sup>1)</sup>	-
Installation safety factor $\gamma_2$	[-]	1.0	-	-	-	-

<sup>1)</sup> Second prefactor  $\kappa$  corresponds to  $s_R = \text{const}$ .

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### Conclusive Remarks

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**Conclusive Remarks**

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- no reduction factors ( $\kappa, \gamma_2$ )  $\rightarrow p_f \ll 10^{-6}$

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- no reduction factors ( $\kappa, \gamma_2$ )  $\rightarrow p_f \ll 10^{-6}$
- $\gamma_2 = 1.4, V_R = 8.8\% \rightarrow \kappa = 0.68 - 0.97 (p_f = 10^{-6})$

**ACI WEB SESSIONS**

**Conclusive Remarks**

---

- no reduction factors ( $\kappa, \gamma_2$ )  $\rightarrow p_f \ll 10^{-6}$
- $\gamma_2 = 1.4, V_R = 8.8\% \rightarrow \kappa = 0.68 - 0.97 (p_f = 10^{-6})$
- $V_R$  rises from 8.8% to **15 %**  $\rightarrow p_f$  rises from  $10^{-13}$  to  $10^{-7}$

**ACI WEB SESSIONS**

**Conclusive Remarks**

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- $V_R$  rises from 8.8% to **15 %**  $\rightarrow p_f$  rises from  $10^{-13}$  to  $10^{-7}$
- $V_Q$  rises from 15% to **30%** or  $V_G$  rises from 5% to 10%  $\rightarrow$  hardly an impact on  $p_f$

**ACI WEB SESSIONS**

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---

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- “worst-worst” case scenario:  
 $V_R = 15\%$  and  $V_Q = 30\%$  and  $\gamma_2 = 1.4 \rightarrow p_f > 10^{-6}$

**ACI WEB SESSIONS**

**Conclusive Remarks**

---

- no reduction factors ( $\kappa, \gamma_2$ )  $\rightarrow p_f \ll 10^{-6}$
- $\gamma_2 = 1.4, V_R = 8.8\% \rightarrow \kappa = 0.68 - 0.97 (p_f = 10^{-6})$
- $V_R$  rises from 8.8% to **15 %**  $\rightarrow p_f$  rises from  $10^{-13}$  to  $10^{-7}$
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- “worst-worst” case scenario:  
 $V_R = 15\%$  and  $V_Q = 30\%$  and  $\gamma_2 = 1.4 \rightarrow p_f > 10^{-6}$

Thank you for your kind attention!

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- 355.2-07: Qualification of Post-Installed Mechanical Anchors in Concrete & Commentary
- 349.2R-07: Guide to the Concrete Capacity Design (CCD) Method - Embedment Design Examples
- 503.5R-92: Guide for the Selection of Polymer Adhesives in Concrete (Reapproved 2003)
- SP-103: Anchorage to Concrete
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